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The multi-purpose use of hydro resources

Status of hydroelectricity generation

Report of the Secretary-General

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Abbreviations and symbols used

CO_2	carbon dioxide
GHG	greenhouse gas
GW	gigawatt
kWh	kilowatt-hour
MW	megawatt
non-OECD Europe	Eastern Europe and the former Soviet Union (the present text specifies whenever the Central Asian republics are considered separately from this group of countries)
OECD	Organisation for Economic Cooperation and Development
TWh	terawatt-hour
%	per cent

Introduction

1. Electricity accounts for an increasing share of final energy demand worldwide and this trend is set to continue, especially in developing countries. Although fossil fuels have continued to be the dominant primary energy source for electricity generation worldwide, hydropower has made tangible progress in many countries. Being an indigenous resource and because of its large potential, hydropower can be expected to contribute significantly to electricity generation in a large number of countries in the developing world, especially in Africa and Asia.

2. Almost without exception, electricity demand in developing countries has been rising rapidly and there is an ever-widening gap between supply and demand. Electricity has increasingly assumed greater importance in the total energy mix of developing countries, as adequate and reliable electric power is central to economic and social development.

3. Hydroelectric power may have reached a mature state of development in most Organisation for Economic Cooperation and Development (OECD) countries (see figure I for net exploitable hydropower resources and percentage exploited), while in the developing world there remains a huge potential for further development. However, concerns about environmental impacts and land requirements for reservoirs have recently constrained multilateral assistance in hydropower development in developing countries. This should be examined in the context of the current discussions on carbon emissions and global warming, giving careful consideration to both developmental needs and environmental and social concerns. Hydropower, large-, mini- and micro-scale, is a time-tested source of electricity generation that is relatively free of greenhouse gas (GHG) emissions. In ecological terms, hydroelectricity has many advantages at a time when considerable efforts must be made to reduce GHG emissions.

4. Electric power generation has become the focal point of determined national economic development programmes aimed at accelerating economic growth and social development. Long-term growth in electricity consumption is expected to remain strong in the developing economies mainly as an outgrowth of improving the quality of life of people: rising per capita income levels and increasing use of electricity are unequivocally linked.

Figure I
Extent of development of world hydropower resources

Net exploitable in terawatt-hours per year (TWh/yr) and percentage exploited

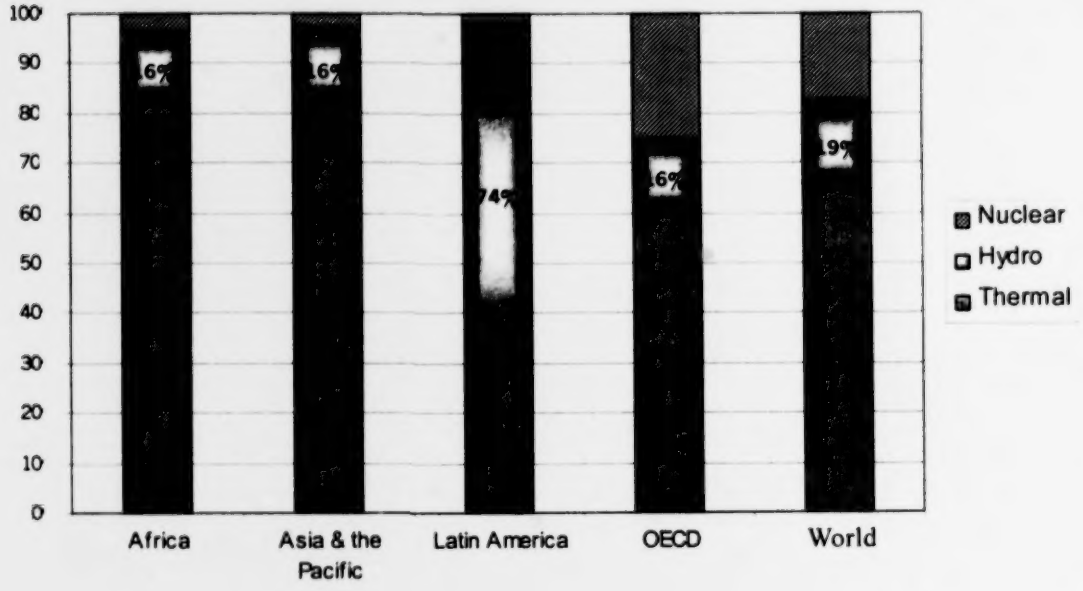
Source: Department of Economic and Social Affairs of the United Nations Secretariat, based on *Energy Statistics Yearbook, 1996* (United Nations publication, Sales No. E/F.99.XVII.3); and *Renewable Energy Resources: Opportunities and Constraints, 1990-2020*, (London, World Energy Council, September 1993).

I. Hydroelectricity generation

5. World installed electric generating capacity stood at about 3,118 million kilowatts (kW) in 1996; and of the world net installed electric generating plants, power plants that use fossil fuels dominate with a share of about 65.2 per cent followed by hydro with a share of about 22.6 per cent, nuclear with a share of 11.2 per cent and other sources (geothermal, wind, solar and biomass) with a share of about 1 per cent. Figure II shows the share of electricity generation by the three major types: in 1996, hydroelectricity generation accounted for about 16 per cent of the total electricity generated in Africa, Asia and the Pacific and OECD countries, while in Latin America the bulk of electricity generation was by hydropower, accounting for about 74 per cent of the total electricity generated.[1]

Figure II
Share of electricity generation by major type in 1996

Percentage

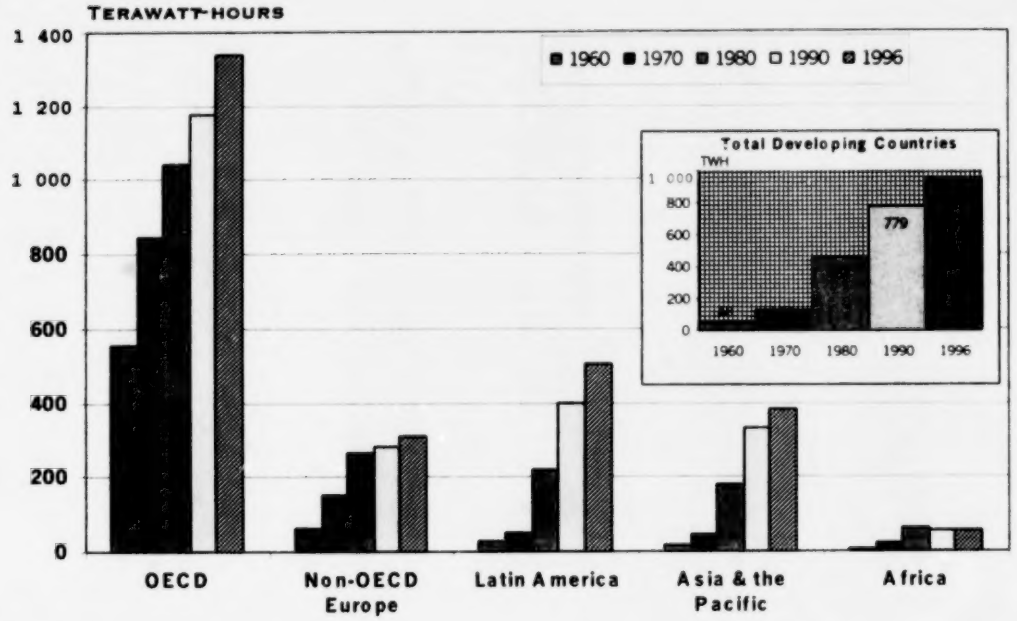


Source: Department of Economic and Social Affairs of the United Nations Secretariat, based on *Energy Statistics Yearbook* (United Nations publication), various issues.

6. Worldwide, the generation of hydroelectricity increased from 2,041,448 million kilowatt-hours (kWh) in 1987 to 2,588,324 million kWh in 1996, an increase of 546,876 million in the 10-year period, for an average annual gain of about 2.3 per cent.[2] The United States Energy Information Agency's International Energy Outlook, 2000, projects an increase in hydroelectricity consumption of 54 per cent between 1997 and 2020, just enough to maintain the hydroelectricity and other renewable sources of energy share at about 8 per cent of the total world energy consumption. Almost half of the increase is expected in the developing world where large-scale hydroelectric projects are being planned and constructed.

7. Total hydroelectricity generation in the different regions between 1960 and 1996 can be seen in figure III. OECD countries were by far the largest producers of hydroelectricity with a total of about 1,337,825 million kWh (about 1,338 terawatt-hours (TWh)) in 1996, while the rest of the world registered hydroelectric power production of about 1,250,499 million kWh. The insert in the chart illustrates the comparatively low level of total hydroelectricity generation in all developing countries — about 944,186 million kWh (approximately 944 TWh), or 70 per cent of total hydroelectricity generation of the OECD countries in 1996.[2]

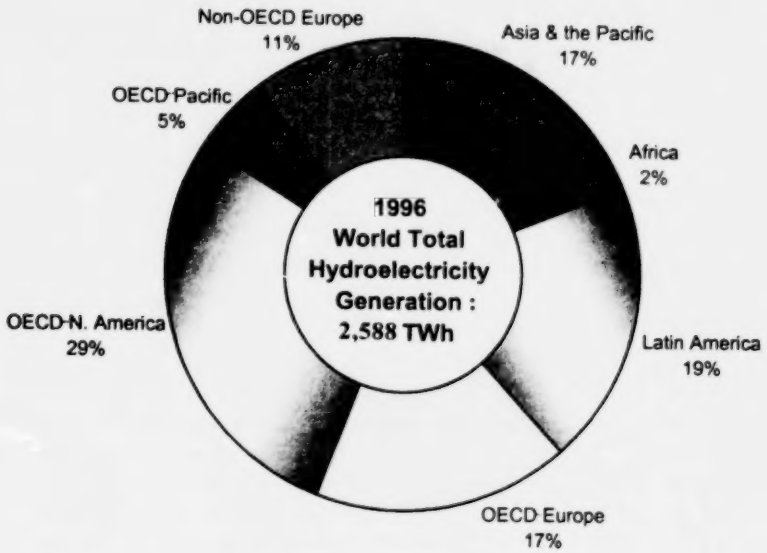
Figure III
Hydroelectricity generation by region, 1960-1996



Source: Department of Economic and Social Affairs of the United Nations Secretariat, based on *Energy Statistics Yearbook* (United Nations publication), various issues.

8. In 1996, OECD-North America countries were the largest producers of hydroelectricity with a total production of about 728,828 million kWh, constituting a 29 per cent share of the world total hydroelectricity generation, followed by Latin America with about 502,222 million kWh, constituting a 19 per cent share. OECD-Europe and the Asia and the Pacific countries accounted for about a 17 per cent share each of the world total hydroelectricity generation. Other regional shares were: non-OECD Europe, 11 per cent; OECD-Pacific, 5 per cent; and Africa, 2 per cent (see figure IV and table). Canada, the United States of America, Brazil, China and the Russian Federation were the five largest producers of hydroelectric power in 1996. Their combined hydroelectricity generation accounted for more than half of the world total.[1]

Figure IV
Regional shares of hydroelectricity generation in 1996



Source: Department of Economic and Social Affairs of the United Nations Secretariat, based on *Energy Statistics Yearbook, 1996* (United Nations publication, Sales No. E/F.99.XVII.3).

Regional hydroelectricity generation, 1996
(Millions of kilowatt-hours)

World	2 588 324
Asia and the Pacific	433 347
Africa	58 779
Latin America	502 222
OECD-Europe	452 466
OECD-North America	728 828
OECD-Pacific	136 054
Non-OECD Europe	276 628

Source: Department of Economic and Social Affairs of the United Nations Secretariat, based on *Energy Statistics Yearbook, 1996* (United Nations publication, Sales No. E/F.99.XVII.3).

II. Hydroelectricity developments: developing world

9. Many hydropower projects are under way or are being planned for construction in several countries of the developing world. The more significant hydroelectricity projects in the different regions of the developing world are highlighted below. Apparently, the development of those hydroelectric facilities would contribute significantly towards sustaining the growth of renewable energy in the foreseeable future.

A. Asia and the Pacific

10. Asia's water resources constitute a vast potential, both for generating hydroelectricity and for irrigation. Several major river systems have excellent hydroelectric potential, and lend themselves to construction of dams with low heads and great volumes of flow. However, seasonal variation in precipitation is a critical factor in developing most of those sites. Hydrologic flows well below anticipated levels for extended periods as a result of drought will lead to severe drops in hydropower output, causing major uncertainty in revenues from hydropower.

11. Several hydroelectric projects are currently under way in the region: China, India, the Lao People's Democratic Republic, Malaysia and Viet Nam all have plans to add large hydroelectricity facilities in the next decade or so. In China, this would amount to over 30 gigawatts (GW) of installed generating capacity. Construction on the 18.2 GW Three Gorges Dam is in its second phase at the end of which the dam will start generating electricity. Upon completion in 2009, the dam is expected to produce as much as 85,000 million kWh of electricity per year. China has announced plans to develop 12 major hydroelectric bases in the country.[3]

12. In India, hydropower constitutes almost 22 per cent (21,104 megawatts (MW) out of 96,803 MW in 1996) of the total installed electricity generation capacity.[1] There are plans to increase hydroelectric capacity substantially in the next few years — by about 35.5 GW by 2012. Twelve large-scale projects adding up to 4,000 MW of installed capacity are apparently under way and scheduled for completion a few years hence. India is facing serious power supply problems with current generation estimated at about 30 per cent below demand. As a consequence, India is faced with the need to invest heavily in new electric generating capacity. India has forecast that total additions of 111,500 MW will be needed by 2007.[4]

13. Several hydroelectric projects have also been introduced in other countries of the region. In Viet Nam, hydroelectricity currently accounts for about 60 per cent of the country's total electricity generating capacity of about 5,000 MW and construction of a 3,600 MW hydropower plant to be operational in a decade or so is being planned. Malaysia has resurrected plans for a large-scale hydroelectric project in Sarawak, although the project has been scaled down to 500 MW of generating capacity. Thailand has reached agreement with the Lao People's Democratic Republic to purchase additional electricity from hydropower stations in the Lao People's Democratic Republic.[5]

14. The potential hydroelectric resource of Nepal has been estimated as being as high as 83,000 MW, although less than 1 per cent has been developed. A 144 MW hydropower project is under way with financing from the Asian Development Bank and the Japanese Government; and India and Nepal have reached an agreement for

joint development of hydroelectric projects, as India is a prime potential market.[6] India will also be developing a number of hydroelectric projects in Bhutan within the next decade so as to be able to import electricity into several Indian States on the country's eastern grid. Sri Lanka is almost totally reliant on hydropower for its electricity, making it vulnerable to fluctuations in rainfall.[5]

15. In the Islamic Republic of Iran, it is estimated that some 6,000 MW of new hydroelectric capacity could be installed by 2020.[5]

B. Africa

16. In many African countries, the hydroelectricity share of installed electricity generating capacity is quite high and is projected to double in the next two decades: in the Democratic Republic of the Congo, Côte d'Ivoire, Ethiopia, Mozambique and Zambia, virtually all grid-connected electricity generation comes from hydroelectricity.[7]

17. In East Africa, Ethiopia has plans to significantly increase the country's electricity-generating capacity. A 34 MW hydroelectric plant in western Ethiopia has been completed, while other existing facilities are being upgraded. Under construction are 184 MW and 73 MW hydroelectric facilities; a 150 MW hydroelectric facility on the Gojeb river is expected to become operational by 2003 and additional hydroelectric facilities are planned. In the northern Sudan, a 300 MW hydroelectric power plant located on the Nile is planned and adequate financing for it has apparently been secured. In southern Uganda, on the Nile, the 180 MW Owens Falls hydroelectric facility is being expanded to include an additional 200 MW of generating capacity. Another 250 MW facility on the Nile could become operational by 2002 and will be the largest of several hydroelectric independent power producer (IPP) projects currently being developed in Uganda. A 180 MW hydroelectric project is being planned in north-western Uganda as well as a smaller facility of 10-12 MW.[7]

18. In Southern Africa, Angola's generation capacity will nearly double when the 520 MW Capanda hydroelectric facility is completed. The Lesotho Highlands Water Project, which involves the construction of dams, tunnels and pipelines, is designed to include a total of 274 MW of hydroelectric generating capacity, and an 80 MW hydro facility as a first phase is already in operation. Zambia plans to rehabilitate the generation facilities at Victoria Falls and expects to restore the facility to its full generating capacity of 108 MW.[7]

19. In West Africa, Ghana has plans for an additional hydroelectric facility to be located on the Black Volta River and the facility will have a generating capacity of 400 MW and possibly provide power exports to Burkina Faso, Côte d'Ivoire and Mali. The 75 MW Garafi hydroelectric facility was inaugurated in Guinea in July 1999. It is the country's largest hydroelectric facility and will supply power to Conakry, Guinea's capital. Plans for a larger (900 MW) facility downstream of Garafi on the Konkoure River are being discussed.[7]

20. In Central Africa, the Democratic Republic of the Congo plans to further expand the Inga hydroelectric facility located on the Congo River. The 2,000 MW Inga II plant and the 40,000-MW Grand Inga facility are intended primarily for power exports to Southern Africa. The combined capacity of these two projects is

nearly as large as South Africa's current installed capacity. Other interconnections are currently under way or planned. The Angola-Namibia Kunene River hydroelectric project will consist of a 200-380 MW generating facility that supplies power to Angola, Namibia and South Africa.[7]

21. In North Africa, in Egypt, hydroelectricity from three hydro plants on the Aswan account for about 51 per cent of the country's total electricity generating capacity. However, very little growth in installed hydroelectric capacity is expected in the next few years in Egypt.[8]

C. Latin America

22. In Central and South America, primarily in Brazil, Chile, Colombia, Paraguay, Peru and Venezuela, hydroelectric dams account for 50 per cent or more of the total installed generating capacity, and there are plans to add substantial capacity in several countries of the region. In Argentina, hydropower accounted for about 43 per cent of installed electricity generating capacity.[9]

23. In Chile, hydropower from westward-flowing rivers from the Andes Mountains is its largest electricity source, constituting about 80 per cent of installed electricity generation capacity. The major drought from late 1997 until well into 1999 severely impacted on the country's electricity sector, during which time rolling blackouts were in effect in Santiago, the capital city. As a result, Chile is now working to diversify its primary energy sources for electricity generation.[9]

24. Brazil's main source of electricity comes from hydropower, providing roughly 95 per cent of the country's electrical energy. Along with Paraguay, Brazil maintains the world's largest hydro complex, the Itaipu facility, with a capacity of 12,000 MW.[9]

III. Small-scale hydropower

25. Almost all developing countries are under political and social pressure to supply electricity to scattered rural areas. Rural electricity supply is often constrained by low population densities and the very low purchasing power of rural people, which limit the choice of commercially viable decentralized supply options. In respect of the consideration of the lowest cost of providing electricity to rural areas, decentralized mini- and micro-hydro plants can be an attractive option for integrating rural areas into a "local grid" system.

26. Mini-hydropower, with capacities between 0.5 and 2 MW, is an increasingly attractive means of generating primary electricity, using the water resources of small rivers, particularly in areas remote from the national grid. Mini-hydropower is a well-developed technology, aided by new design techniques, and is appropriate for both developed and developing countries.

27. The United Nations has completed a survey to evaluate mini-hydropower resources in 46 developing nations, the objective of which was to identify technically feasible and economically attractive projects for supplying electricity to isolated areas. The results of the survey indicate the vast scope for this technology in many regions, and follow-up projects at some sites have demonstrated the need to

take account of the environmental, social and economic dimensions in developing these resources.

28. Micro-hydropower systems consisting of easily built dams on small rivers and streams, using landfill and rocks and connected to micro-turbines and generators with capacities ranging from 1 to 50 kW, can meet the needs of one family or several households. A typical micro-hydroelectricity generating system would be a "stream engine",[10] where water from a stream is channelled into a pipeline so as to gain sufficient head to power the system consisting of a brushless permanent magnet alternator coupled to a rugged bronze turbo wheel and universal nozzles. It can be used for battery-based power systems, with electricity generated at a steady rate and stored in batteries. At sites where sufficient head and flow rates are available, higher voltages can be generated to transmit over longer distances and the voltage stepped down to charge batteries.

IV. Conclusions

29. In order to meet the challenges of sustainable development, all technology options for electricity generation should be kept open. Hydro derives its energy from a renewable resource and is therefore, by definition, renewable; and thus renewable hydroelectricity has significant potential to reduce emission of GHGs by substituting for existing and planned fossil fuel fired generation. Expanding the use of hydropower is cost-effective, does not create market distortions and can sharply reduce carbon dioxide (CO_2) emissions from the electric power sector.

30. Nonetheless, there are environmental drawbacks associated with hydropower, especially as regards the effect of dams on river ecosystems. Environmental degradations, such as ecological changes, effects on fish and reduced water flow, need to be addressed. For large-scale hydropower development, population displacement is conspicuous: careful site selection and project design limiting the maximum reservoir level, for example, may minimize the displacement.

31. Environmental considerations, such as carbon emissions particularly in the case of fossil fuels and habitat destruction in the case of hydroelectric dams, for instance, can complicate the choice of fuels for new power plants. Frequently, financial and social considerations also come into play.

Notes

[1] *Energy Statistics Yearbook, 1996* (United Nations publication, Sales No. E/F.99.XVII.3).

[2] *Energy Statistics Yearbook* (United Nations publication), various issues.

[3] Three Gorges Dam, China, web site (*http://www.coxnews.com/washington/gorges.htm*).

[4] South Asia Regional Review, United States Energy Information Agency (EIA), web site (*http://www.eia.doe.gov/*).

[5] United States Energy Information Agency (EIA), *International Energy Outlook 2000*, March 2000, p. 93.

[6] Statement made by the delegation of Nepal at the session of the Ad Hoc Open-Ended Intergovernmental Group of Experts on Energy and Sustainable Development, 6-10 March 2000, New York.

[7] Energy in Africa, EIA web site (*http://www.eia.doe.gov/*).

[8] See *International Energy Outlook 2000* ..., p. 107.

[9] EIA Country Analysis Briefs: Central and South America web site (*http://www.eia.doe.gov/*).

[10] Energy systems and design: innovative micro-hydro systems since 1980, web site (*http://www.microhydropower.com*).